Electron Scattering off ^{4}He with Three-Nucleon Forces

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Abstract

An *ab initio* calculation of the ^{4}He (e,e') inelastic longitudinal response function R_L is presented. Realistic two- and three-body forces are used. The four-body continuum dynamics is treated rigorously with the help of the Lorentz integral transform. The three-nucleon force reduces the quasi-elastic peak height by about 10% for momentum transfers q between 300 and 500 MeV/c. Experimental data are well described, but not sufficiently precise to resolve this effect. The reduction due to the three-nucleon force increases significantly at lower q reaching up to about 40% at $q = 100$ MeV/c. However, at such q values data are missing.

Key words: three-nucleon force, electron scattering, Lorentz integral transform
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The longitudinal response function R_L is given by

$$R_L(\omega, q) = \sum\!\!\!\!\!\!\!\int_f |\langle \Psi_f|\hat{\rho}(q)|\Psi_0\rangle|^2 \delta\left(E_f + \frac{q^2}{2M} - E_0 - \omega\right) , \tag{1}$$

where M is the target mass, $|\Psi_{0/f}\rangle$ and $E_{0/f}$ denote the four-body initial and final state wave functions and energies, respectively, while ω and q are the energy and momentum transfers. The charge density operator ρ is defined as

$$\hat{\rho}(q) = \frac{e}{2} \sum_i (1 + \tau_i^3) \exp[i\mathbf{q} \cdot \mathbf{r}_i] , \tag{2}$$

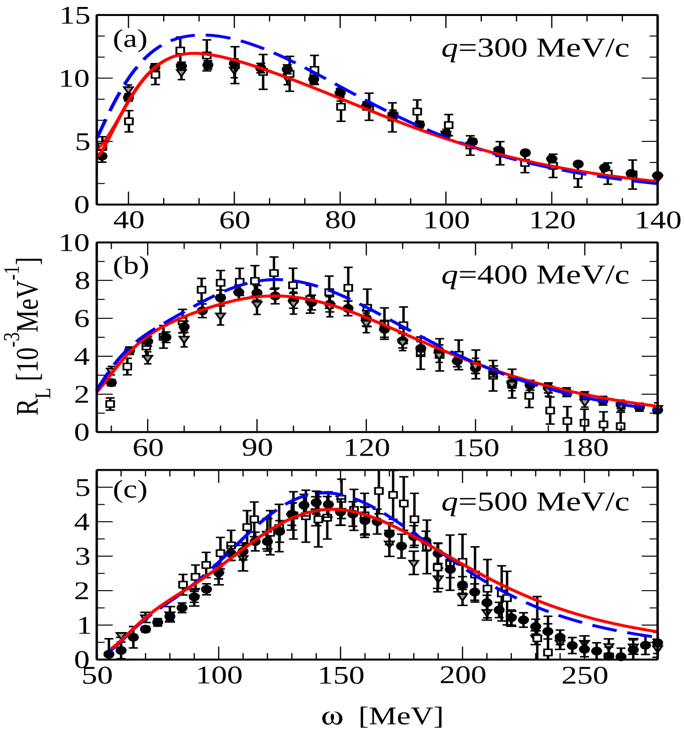

Fig. 1. $R_L(\omega, q)$ at various q. Dashed lines: AV18; solid lines: AV18+UIX. Data from Bates [9] (squares), Saclay [10] (circles) and world data-set from [11] (triangles).

where e is the proton charge and τ_i^3 the isospin third component of nucleon i. For a conventional calculation of R_L one would need to know explicitly the four-body continuum state wave functions Ψ_f. In the Lorentz integral transform (LIT) method [1] this difficulty is circumvented by considering instead of $R_L(\omega, q)$ an integral transform $\mathcal{L}_L(\sigma, q)$ with a Lorentzian kernel defined for a complex parameter $\sigma = \sigma_R + i\,\sigma_I$, which is then inverted in order to obtain $R_L(\omega, q)$ (see review [2]).

For the calculation of R_L we take a realistic nuclear interaction consisting in the AV18 two-nucleon potential [3] and the UIX three-nucleon force (3NF) [4]. The ^{4}He ground-state wave function and the LIT are calculated using expansions in hyperspherical harmonics with the EIHH [5,6] and Lanczos [7] techniques (for more information concerning the calculation see [8]).

In Fig. 1 we show R_L at 300 MeV/c $\leq q \leq$ 500 MeV/c. One sees that the 3NF reduces the quasi-elastic peak strength by about 10%. Experimental data are described quite well by our full result, but they are not precise enough to resolve the 3NF effect. In Fig. 2 we illustrate R_L at lower q. One readily notes a very strong reduction at lower energies due to the 3NF, which reaches up to about 40%. The reduction cannot be attributed to a simple binding effect as becomes evident from the also shown R_L results with a semirealistic NN force (MT potential [12]). In fact, ^{4}He binding energies are 24.3, 28.4, and 30.6 MeV for AV18, AV18+UIX, and MT potentials, respectively. Even though the MT energy is closer to that of AV18+UIX, the MT R_L is more similar to the R_L of AV18

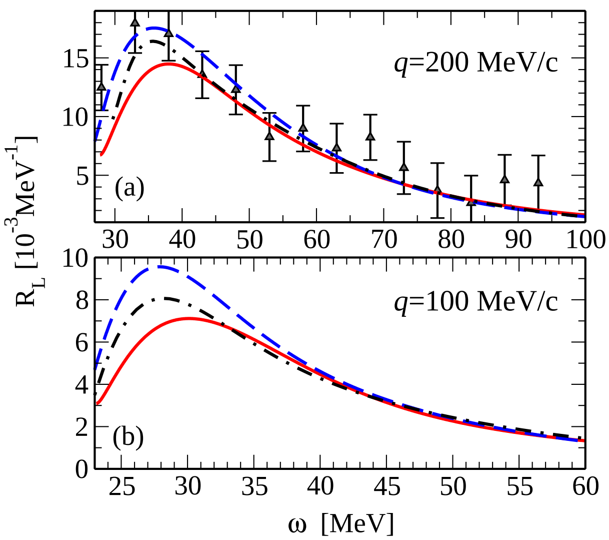

Fig. 2. $R_L(\omega, q)$ at various q: AV18 (dashed), AV18+UIX (solid), MT (dash-dotted). Data in (a) from [13].

than to the AV18+UIX R_L. At lower q there is only one data set at 200 MeV/c [13], which is not sufficiently precise to draw concrete conclusions.

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